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STORAGE AND HANDLING OF FULL TREES IN A CENTRAL PROCESSING PLANT

RENEWABLE ENERGY BRANCH

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Preface

This report is an analysis of the significance of problems which the forest industry anticipated might develop as forest harvesting and processing operations were changed to recover branches and tops for energy. Particular concern was expressed over excess breakage when trees were handled with branches and tops still attached (rather than as delimbed stems or logs) until they reach a central plant for processing. Another source of concern was the risk of fires in inventories of trees with branches and tops attached. The report delves in greater detail into these two areas, which were left basically untouched in previous analyses of central processing of full trees.

The report recommends work methods which will reduce breakage and fire risk in full tree handling, transportation and storage. The report analysis is based on a centralized full tree processing system of the type designed by the Logging Development Corporation or those used in West Germany and parts of the Soviet Union.

The report was prepared on the basis of both field visits and telephone interviews with forest industry personnel who had experience with full tree handling and storage. It should be noted that in no case was any installation found to be storing a full tree inventory in a central location of the size envisioned for the plant upon which this report is based. The methods and strategies recommended in this report, therefore, need to be tested.

SUMMARY

There have been many studies in the recent past assessing the benefits and costs of technologies which make it possible to transfer the processing operations normally carried out on trees in the woods to a central location. The majority of these studies have concentrated on full-tree central processing plants which produce both conventional logs and a variety of other products such as pulp chips and energy biomass from full trees which have been transported from the forest to the plant. Some concern has been expressed over the possibility of experiencing incremental breakage when handling and hauling full trees rather than tree lengths or shortwood and of fire risk in inventories of full trees stored at a central processing plant.

Although no scientific comparisons of breakage in handling and fire risk in storage of full trees and tree lengths have been prepared, the concern expressed over incremental fire risk and breakage when storing and handling full trees appears to have some justification. This report assesses the causes of the breakage and incremental fire risk and proposes means of controlling or reducing them.

Breakage in any operation was found to be primarily a function of the following factors:

1) Operator skill
2) Choice of equipment
3) Length and season of storage
4) Tree species and condition

Breakage control strategies were developed based on these factors. The emphasis was placed on reducing the frequency handling by running as "hot" an operation as possible and shortening the stay in inventory during winter months. Certain high-breakage activities such as piling with a skidder at roadside should be eliminated.

Fire risk and severity was found to be a function of the following variables:

1) Moisture content of trees
2) Fuelbed continuity
3) Availability of ignition sources
4) Lag time between ignition and extinction

Fire prevention and control strategies based on these factors were developed. The emphasis was placed on creating breaks in fuel, limiting ignition sources and controlling inventory moisture content by reducing storage time or by direct application of water where required.

SUMMARY (CONT'D)

A preliminary experimental design for a test of the difference in breakage when handling full trees or tree lengths was created. The need to avoid sampling during the initial start-up phase of the central processing plant system in order to prevent the creation of a bias was stressed.

It was concluded that neither breakage nor fire risk was likely to impede the development of the central processing concept. It was also concluded that a large number of other factors not related to energy production would play a key role in the development of the concept.

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Executive Summary

A number of studies have been performed in the last decade assessing the economic and technical feasibility of harvesting full trees and transporting them using trucks to a central plant for processing into conventional products and into energy biomass. Although the results of these reports have been largely positive, some concern existed over the possibility of increased tree breakage during handling and fire risk during storage. This report assesses these concerns and proposes control methods and strategies where these are felt to be necessary. The report also presents a preliminary experimental design to test the incremental breakage when handling full trees during a proposed test of a prototype processing plant.

The conclusions and recommendations of this report are derived from literature searches, telephone interviews with forest industry managers and from field visits to central processing installations.

Most eastern forest managers felt that breakage in full tree handling would be marginally greater than in tree-length or shortwood handling. Skidding, piling, loading and unloading of full trees were identified as major sources of breakage. The use of a loader which holds trees by the centre rather than the butt was recommended. The use of a skidder for piling at roadside was not recommended.

In the larger timber found in Western Canada, breakage could, it was felt by managers, be reduced by bucking in a flat central landing rather than at roadside.

An inventory handling strategy was developed to reduce breakage and fire risk. This was based on the following guidelines:

A) Move wood from trucks to the processing deck rather than from the truck to inventory and then to the processing deck.

B) When snow and ice cover the inventory, process the wood most recently stored first in order to reduce chances of having severely cemented tops and branches.

C) When wood must be obtained from inventory during hot, dry periods the inventory longest in stock should be used first to avoid accumulation of very dry and brittle wood.

The protection of stored full trees from fire is based upon the following recommendations:

1) Sources of heat, spark and flame should be tightly controlled in the mill yard to prevent fires from starting.

Executive Summary (cont'd)

2) The inventory should be under observation at all times to make possible early detection of fires. This observation may be supplemented by infra-red scanners to detect "hot spots".

3) Trained personnel should be available to use properly maintained fire fighting equipment in the event of a fire.

4) Moisture content in the stored full trees should be held above critical levels by giving priority of use to dry portions of the inventory and by applying water directly if required.

5) Fire breaks should be provided in the stored trees to limit the spread of fires and ease firefighting.

6) The storage yard and equipment used therein should be cleared of accumulated debris to reduce the risk of fire.

7) The size of the inventory held in storage should be reduced as much as possible to limit the quantity of wood at risk (and to reduce holding costs).

Other considerations in storage and handling of full trees include:

1) The use of truck trailers which are enclosed on both the bottom and sides near the butt-end(s) of the load would help to reduce the chance of butts dropping to the road due to poor butt alignment in full-tree loads.

2) The use of a 15-20 cm block in the rear portion of trailers could raise the tops of full trees (in long loads) sufficiently to prevent fine road particles from being "swept" from the surface and thereby reduce road costs.

3) The branches and tops of full tree loads protrude beyond the edges of the trailer and may cause safety hazards to passing or encountering vehicles. The use of enclosed trailers may reduce this hazard and, if equipped with compacting devices, increase the merchantable payload.

A preliminary experimental design for a test of breakage in the proposed prototype plant was developed. The design involves a two-stage sample. The first stage is a pre-sample done to determine whether the difference in breakage is sufficiently large to warrant futher testing and, if so, to determine the sample size required in the main sample. It is stressed that a significant period must be allowed after the commencement of operations for production methods to be debugged and personnel to become accustomed to handling full trees before the sample is taken. This will remove a major source of error.

RESUME

Un certain nombre d'études ont été effectuées au cours de la dernière décennie sur la faisabilité économique et technique de l'abattage et du transport d'arbres entiers combustibles par camions vers une usine de transformation en produits traditionnels ou combustibles biomassiques. Bien que les conclusions de ces rapports aient été très positives, il reste à régler la question du risque de bris plus élevé au cours de la manutention et du risque d'incendie durant le stockage. Ce rapport traite ces deux sujets et propose plusieurs méthodes de contrôle ainsi que des stratégies lorsqu'elles sont nécessaires. Ce rapport présente également un concept expérimental préliminaire qui vise à réduire les bris résultant de la manutention des arbres entiers et qui a été mis au point au cours d'un essai de prototype d'usine.

Les conclusions et les recommandations de ce rapport proviennent des recherches bibliographiques, des interviews effectués au téléphone avec plusieurs dirigeants de l'industrie forestière ainsi que des visites sur place dans des usines.

La plupart des dirigeants des industries forestières de l'Est pensent que les bris seraient légèrement supérieurs lors de la manipulation d'arbres entiers plutôt qu'avec des pièces de faible longueur ou de longueur d'arbre. Les débusquage, la mise en piles, le chargement et le déchargement des arbres entiers ont été rapportés comme sources principales des bris. L'utilisation d'un chargeur qui tient les arbres par le centre plutôt que par les extrémités a été recommandée. L'utilisation d'une débusqueuse pour l'empilement sur le bord de la route n'est pas recommandée.

Pour les grands arbres de l'ouest du Canada, on pourrait réduire les bris des arbres, selon les dirigeants, en les débitant sur un terrain plat plutôt que sur le bord de la route.

On a mis au point une stratégie de manutention de l'inventaire pour réduire les bris et les risques d'incendie. Cette stratégie est basée sur les recommandations suivantes:

A) Transporter le bois des camions à la plateforme de transformation plutôt que du camion à la pile de stockage puis de là à la plateforme.

B) Lorsque la pile de stockage est recouverte de neige et de glace, traiter le bois stocké le plus récemment d'abord afin de réduire risques de collage des branches et des cîmes.

C) Lorsque le bois doit être prélevé des piles de stockage au cours des périodes de chaleur et de sécheresse, il faut prendre en premier celui des piles les plus anciennes pour éviter l'accumulation de bois trop sec et trop cassant.

La protection contre le feu des arbres entiers stockés est basée sur les recommandations suivantes:

1) Il faut surveiller attentivement les sources de chaleur, d'étincelles et de flammes dans la cours de l'usine pour éviter les incendies.

2) Les piles entreposées doivent être surveillées en permanence pour détecter le plus rapidement possible un début d'incendie. L'observation peut se faire automatiquement à l'aide d'un appareil à balayage infrarouge pour détecter les points chauds.

3) Le personnel ayant reçu la formation nécessaire doit être disponible pour faire fonctionner l'équipement de lutte contre les incendies qui doit être convenablement entretenu.

4) La teneur en humidité des arbres entiers stockés doit être maintenue au-dessus du niveau critique en utilisant d'abord les parties sèches des piles et en arrosant d'eau au besoin.

5) Il doit y avoir des coupe-feu dans la zone de stockage des arbres pour limiter la propagation d'un incendie et faciliter son extinction.

6) Afin de réduire les risques d'incendie, la cour de stockage et les équipements utilisés dans celle-ci ne doivent pas comporter des débris accumulés.

7) La taille des piles doit être réduite le plus possible pour limiter la quantité de bois présentant un risque (et réduire les coûts d'immibolisation).

Les autres considérations concernant le stockage et la manutention des arbres entiers sont les suivantes:

1) L'utilisation de semi-remorques munis de ridelles retenant les extrémités de la charge permettrait de réduire les risques de chute sur la route dus à un mauvais alignement des extrémités des arbres.

2) L'utilisation de blocs de 15 à 20 cm à l'arrière des remorques permettrait d'élever suffisamment la cîme des arbres entiers (pour les charges très longues) afin d'éviter le balayage des particules fines de la route réduisant le coût d'entretien de la route.

3) Les branches et les cîmes des arbres entiers qui dépasssent les côtés de la remorque peuvent présenter un danger pour les véhicules qui dépassent ou viennent en sens inverse. L'utilisation de remorques fermées peut réduire ce risque. Si elles sont de plus équipées de dispositifs de compactage, on pourra alors augmenter la charge utile.

Un concept expérimental préliminaire visant à limiter les bris a été mis au point ainsi qu'une usine pilote. Ce concept comprend un échantillonnage en deux étapes. La première étape est un pré-échantillonnage permettant de déterminer si la différence des bris est suffisante pour justifier de nouveaux essais et, si c'est le cas, pour déterminer la taille de l'échantillonnage nécessaire. On insiste sur le fait qu'une période suffisante doit être allouée après le commencement des opérations afin de corriger les erreurs des méthodes de production et afin de permettre au personnel de se familiariser avec la manutention des arbres entiers avant d'effectuer un échantillonnage. On supprimera ainsi une source importante d'erreur.

Section 1.0 Introduction

When interest in alternate, renewable energy sources grew in the wake of the 1973 embargo of oil supplies by the Organization of Petroleum Exporting Countries, forest biomass was identified as one of Canada's most promising options.

Of the many means of recovering forest biomass for use as a fuel, collection at a full-tree central processing plant has been identified as one of the most economically attractive (16,24,28). Although many studies of the central processing concept have been carried out, questions remained regarding the potential problems which might be encountered in handling full trees. The central processing concept would require fundamental changes in the harvesting, processing, transportation and storage of forest products. Concern also exists over the danger of increased breakage when handling full trees rather than tree lengths or shortwood. The central processing plants considered by Routhier (24) and Zundel (28) would require storage of 50,000 and 80,000 m^3 of full trees respectively during the spring break-up period. This inventory would have a value of $1.25-3.2 million (assuming delivered wood costs of $25-40/$m^3$. The value of this inventory requires that the questions regarding fire prevention and control be addressed.

This project was undertaken to address these concerns. In order to achieve this, four activities were carried out:

1) The literature was surveyed to compile existing information on full-tree handling and storage.

2) Forest industry personnel with experience in handling and storage of full trees were interviewed to assess which concerns were valid and what strategies were implemented to address them.

3) Central processing yards in Canada and the United States were visited in order to identify strategies used to control breakage in handling and fire hazards in storage. This process also yielded considerable pictorial material useful in information transfer.

4) Preliminary experimental designs were prepared to measure incremental breakage in full-tree handling (compared to the handling of conventional forms such as tree lengths).

Section 2.0 Literature Review

Although the subject of centralized processing of full trees has received considerable study, very little attention has been focused on the question of loss of merchantable wood due to breakage in handling and fires in mill inventory.

Routhier (24) carried out field tests to measure both the number of stems exhibiting breakage and the merchantable volume loss in full trees. This field testing measured the quantity of merchantable wood left after piles of full trees in inventory at roadside and at a processing yard were moved by loaders. The amount of merchantable wood found in these two tests were 0.3-2.4% and 0.1% of the wood handled respectively. Strong inter-specific differences were found with balsam fir (Abies balsamea (L) Mill.) exhibiting more breakage than black spruce (Picea mariana (Mill.) B.S.P.). The length of time during which trees were stored in winter conditions was also significant due to the accumulation of snow and ice which cemented tops of full trees together. In trees severely affected by spruce budworm (Choristoneura fumiferana), breakage was higher in all conditions. The breakage in tree lengths handled similarly was,

however, not measured. It is, therefore, impossible to assess the incremental breakage when handling full trees from this study. The percentages of merchantable volume loss due to breakage do, however, appear to be small (interviews with industry personnel, discussed later, also lead to this conclusion.)

Hedin (10) did not test the incremental breakage in central processing yards, but reported that observations made during the field work indicated that the hypothesis which proposes that full tree processing in central yards may reduce breakage might be valid. It is important to note that the majority of the operations considered in the study handled trees which were much larger than those handled in Eastern Canadian operations. The larger size of the trees and the slope of many western logging areas may lead to greater breakage and merchantable volume loss when bucking is carried out at the stump or roadside.

Johansson and Ericsson (14) indicated that fibre yields might increase by 10-15% when small trees were processed in a central processing plant which delimbed trees in drum debarkers rather than being delimbed and topped either in the stump area or at roadside. The majority of this increase in fibre yield is probably due to the utilization of the fibre in the top portion of the tree which is commonly left in the stump area. This observation implies that loss due to breakage may be offset by the recovery of top wood if drum debarkers are used for delimbing. This would not necessarily be the case if sliding

boom delimbers equipped with shears were used (e.g. the plant described in (8)), since the top wood might be chipped along with branches in a hog or chipper.

The absence of reports of breakage in analyses of full tree handling and central processing (15,16,2,1) may reflect a perceived insignificance of this factor. It should be noted that with the exception of (16), these studies were carried out neither in the winter nor in the boreal forest.

Section 3.0 Industry Interviews and Visits

The next section will analyze interviews held with industry woodlands managers to assess the perceived significance of breakage in both full-tree and tree-length handling. In all interviews with industry forest harvesting operation managers, the following questions were asked to determine the significance of breakage during full-tree and conventional handling:

1) What percentage of stems handled experience breakage in the merchantable portion and is this a significant problem?

2) Where does breakage occur in the handling process?

3) Is there a significant difference in breakage when handling full trees instead of tree lengths?

These questions were posed to managers in Eastern and Western Canada since the forest resource, terrain and harvesting systems differ in the two regions. The results of the interviews and visits for each region are treated separately since the results are substantially different.

Section 3.1 Eastern Canada

All industry managers interviewed estimated that no more than 5% of stems handled as tree lengths would be broken in the merchantable portion of the stems (6,13,20,21). Ouellet (20) indicated that in black spruce breakage would not exceed 2% of stems, while in timber killed by spruce budworm, breakage would be higher. Lebreux (17) indicated that breakage would be unlikely to exceed 1% in timber delimbed with sliding-boom delimbers but might reach 5% in trees delimbed manually and piled at the landing with a skidder.

Many managers expressed the opinion that under most conditions breakage in full trees would not significantly exceed that in tree lengths (6,21,22). Many of the same managers indicated that when snow and ice is allowed to accumulate in the tops and branches of full trees, breakage could significantly increase. Lebreux (17) indicated that in an operation harvesting mainly balsam fir (85%), the woodlands operations were halted each winter due to unacceptable breakage losses.

Several processes in harvesting systems were identified as major sources of breakage. Considerable breakage may occur in skidding (21,20). Piling of trees at the roadside using skidder blades was identified as a major source of breakage (17). This was also noted in (8) and (28). Loading and unloading were identified as sources of breakage by all managers interviewed. It was, however, felt that breakage in loading could be controlled by eliminating the piling of trees using a skidder blade since this process causes intertwining of tops (17). The

selection of a loader which holds the center of trees rather than the butt was also identified as a means of controling breakage (24,8,28). Figures 1 to 11 show the loading process for full trees. Figures 1 to 4 show loading using a heel-boom loader which holds trees near the butt. It is clear from these photos that considerable breakage and difficulty is being experienced by operators using these loaders. It is important, however, to note that in most of the operations from which these pictures came, the loading of full trees was experimental. In operations where full-tree loading with heel-boom loaders is a normal procedure, the breakage and difficulty was much less severe (see Figures 5 to 7) but not altogether eliminated (see Figure 8). Loaders which hold trees near the center of the stem are shown in Figures 9 to 11. The reader should note the apparent ease of handling in these photos.

Although the level of concern exhibited over breakage in Eastern Canada was generally low in black spruce and jack pine (except after extended winter storage), it was clear that balsam fir was susceptible to severe breakage. This was especially evident where balsam fir timber had been killed by spruce budworm. In the light of the increasing severity of insect infestations in Canada, it is clear that the question of breakage is one to which answers must be found. The control of breakage is dealt with in subsequent sections.

Section 3.2 Western Canada

Western Canadian logging operation managers (as well as one in the U.S. Pacific North-West) indicated that handling full trees and processing them at a central processing plant would reduce breakage compared with conventional log-length handling (11,27) or leave it unchanged. This difference with Eastern operations is due to the different characteristics of the trees and terrain in which logging and processing occurs. The larger timber and steeper slopes may cause significant breakage to occur in the felling of timber (3). This may overshadow the breakage occurring in handling. Figures 12 to 14 demonstrate the difference in timber sizes between western (Figures 12 and 13) and eastern loads.

Section 3.3 Understanding the Handling Process

The processing and handling which trees undergo before conversion from roundwood into final products is broken into the steps listed below:

1) Felling
2) Delimbing
3) Topping
4) Choking/Whinching
5) Bunching
6) Skidding/Forwarding
7) Piling
8) Bucking (slashing)
9) Loading
10) Hauling
11) Unloading
12) Retrieval from inventory/handling
13) Debarking

Since one of the objectives of this study is to evaluate incremental breakage when handling full trees rather than other forms of solid forest products (tree lengths, shortwood, log

lengths), only the breakage occurring in steps which are unique to a system which incorporates a central processing plant should be considered. In shortwood systems, steps 1-8 would always be carried out in the stump area. In tree-length systems, steps 1-7 are also carried out in the stump area with delimbed stems being produced at roadside. The bucking may be carried out at roadside or at the mill. In conventional full-tree systems all steps up to 7 except delimbing and topping would be carried out in the stump area. The delimbing and topping would occur at roadside. Bucking could occur at roadside or at the mill. In the central processing case the delimbing, topping and bucking occur at the central processing plant. With the exception of these three steps, all processes which precede loading may be identical for the central processing system and a conventional full-tree harvesting system. It is, therefore, in steps 9-13 which the differences in breakage between conventional and centralized processing systems may be found.

Debarking usually immediatly precedes the final processing of roundwood and is, therefore, usually done after delimbing, topping and bucking. This eliminates, in most cases, the opportunity for excess breakage when debarking roundwood which was converted from full trees at a central processing plant. Since trees are held static on a logging trailer during hauling, it is unlikely that significant breakage in the merchantable area of the stem will occur during this process. The exception to this rule is the case in which loads are mechanically compacted (see (25) for a description of this kind of equipment). This might increase breakage in merchantable areas and is almost sure

to cause branch breakage. There are, therefore, three processes in which incremental breakage caused by handling full trees is likely to be felt:

1) Loading
2) Unloading
3) Retrieval from inventory

In order to design effective breakage control strategies, these three processes must be considered.

Section 4.0 Breakage Control Strategies

Section 4.1 Control of Breakage in Loading

Of the three processes listed above, loading is the most prone to causing additional breakage in full trees. The loading process is affected by terrain, weather, previous processes and the choice of equipment used to carry it out. There are four means of reducing breakage in full-tree loading:

1) Scheduling of Hauling

The loading step should follow the harvesting as closely as possible in order to reduce breakage caused by:

a) Accumulation of snow and ice in branches and tops (24,8,22).
b) Drying of stems, which leads to brittleness (13).

2) Removal of Accumulated Snow

When snow has accumumlated on piles during winter storage, it should be removed before loading is undertaken. Skidders have been used for this purpose (22).

3) Piling of Trees at Roadside

Trees should not be piled using skidder blades since this causes direct breakage (8), and increases the intertwining of tops which leads to breakage during loading (17). Limitations in landing space at roadside may require that piles of full trees be built up to increase the volume of wood per unit area. Should this be the case, it is preferable to run skidders longitudinally over piles to build them up by dropping additional loads in one area rather than piling the trees using the skidder blade. This is especially true when skidders with wide tires are used (13). Another reason to limit the use of skidders to pile trees at roadside is that this process causes branch breakage, thereby reducing the amount of biomass recoverable for the production of energy.

4) Choice of Loading Equipment

The use of heel-boom loaders which hold trees near the base may cause excessive breakage when handling full trees (24,28). For this reason, it is recommended that a loader which holds full trees near the center of the stem be used. Figures 1 to 4 show examples of heel boom loaders holding trees near their bases. Figure 9 to 11 show loaders which hold trees near the center of their stems. Full trees tend to "fan out" when handled by heel-boom loaders (see Figures 1 to 8). This phenomenon does not occur when centre-grab loaders are used (see Figure 11). Center-grab loaders are used in the large number of central processing plants operated in the U.S.S.R. (12). Figure 15 shows a drawing

of the central processing complex of the kind used in the U.S.S.R. This reduction in fanning will reduce the delays in handling full trees and, therefore, reduce the loading cost.

Section 4.2 Control of Breakage in Unloading and in Transfer from Inventory

These two operations have been lumped together in this section since the breakage control recommendations are identical for both and since in some central processing plants both functions may be carried out by one machine (24,7). Breakage in unloading and transfer from inventory may be controlled by the following methods:

1) Choice of Loading Equipment

A center-grab unloader should be used rather than one which holds trees near their bases. The reasons for the use of this kind of unloading technology are described in Section 4.1 above.

2) Removal of Accumulated Snow

When snow accumulates on central processing plant yard inventory, and wood must be moved, as much snow and ice as possible should be removed. A front-end loader might be used for this purpose.

3) Inventory Handling Strategy

The most important means of controlling breakage in these operations is the implementation of a strategy of wood use. This strategy is based on knowledge of three factors of critical importance in influencing breakage (independently of choice of equipment and operator skill):

A) Species mix of wood handled (i.e. fragility).
B) Moisture content (i.e. brittleness).
C) Time of year (i.e. threat of accumulation of snow and ice).

The strategy is composed of three rules which take into account these factors and guide the handling processes. These three "rules" are:

1) Run the unloading and central processing operation as "hot" as possible.

In effect, when possible, wood should be unloaded directly onto the delimber deck (see (24,7)) rather than into inventory. Wood handled by different processes in quick succession is said to have been handled "hot" and wood left for long periods between operations is said to have been "cold decked". Preference should also be given to fragile species such as balsam fir when deciding which loads to place on the delimber deck rather than in inventory (24). This latter guideline may be over-ridden by the capacity of the mill to handle changes in species proportions in the feedstock. Preference should also be given to trees which have been stored over long periods (e.g. over one year) at roadside and may have become brittle as they dried.

This recommendation completely eliminates one step in the handling process for trees which are processed "hot". It also reduces breakage in the 'transfer from inventory' step by reducing the number of fragile and brittle trees to be handled.

2) When snow and ice has covered the trees in inventory and wood must be transfered from inventory for processing, the trees most recently stored should be processed first.

Trees will be less likely to have frozen together in the shorter storage period and will, therefore, be less likely to be

subject to significant breakage. Badly frozen trees may, therefore, have the opportunity to thaw during the warmer end of the spring break-up period, thereby reducing breakage in the inventory.

3) When wood must be obtained from inventory during the hot and dry periods, the oldest stock should be used first.

This will avoid wood becoming brittle and thereby reduce breakage. This will also reduce the fire danger in the inventory (this is dealt with in Section 5.2.4).

Section 5.0 Fire in Stored Full Trees

The storage of full trees bears a greater risk of fire than does the storage of tree lengths or shortwood. This is a function of the lower bulk density and greater surface-area-to-volume ratio of stored full trees. Figure 16 shows a fire in a high-density stand of jack pine. Fires of this intensity in full tree inventories could cause injury to workers, damage to central processing plant facilities, mobile equipment and loss of large quantities of stored wood. Even low-intensity fires can destroy the value of timber by affecting suitability for pulping and certain kinds of sawn lumber.

Interviews with managers of central processing facilities in both Western and Eastern Canada (as well as one in the U.S. Pacific North-West) were asked the following questions:

1) How serious is your concern over fire in stored full trees?
2) Have you ever experienced fires in stored full trees?
3) What methods do you use to protect against fire?

Although none of the managers questioned felt that the danger of fire in inventory was a factor limiting the development of the central processing concept, there was a concensus that fire was a concern in large full-tree inventories (11,26,27,17,22). The lack of serious concern over fire among most of the managers questioned may be a reflection of both perceived and actual risk. It may also be due to the fact that in most operations which process full trees at a central plant, the full-tree inventories are small relative to those which would have to be kept in a plant such as that described in (7). In operations which do (or did) keep large inventories, concern is more serious (22). In regions in which the break-up period is rainy, the concern over fire risk is lower (27).

Section 5.1 Theoretical Basis for Fire Protection

The severity of a fire (from a mill manager's point of view) may be gauged by its intensity and its rate of spread. Rothermel (23) laid down the theoretical and empirical framework for understanding fire behaviour in forest fuels. Many of the factors which influence fire behaviour in forest fuels are outside the control of managers (e.g. Wind speed, physical and chemical characteristics of trees and ambient temperature) once a decision has been made to handle and store full trees. In this analysis only factors over which managers have relatively easy control are discussed. The following equations define the relationship of fire intensity and rate of spread to those factors over which managers may have some control:

Fire Intensity = I = f(1/MC,SV) (1)

MC = moisture content of fuel.

SV = Ratio of surface area to volume.

Rate of Spread = R = f(I,PF,1/D) (2)

I = intensity of fire (as defined in Equation (1)).

PF = propagating heat flux (net rate of heat energy input to fuel).

D = bulk density of fuel bed.

It is also important to note that the area burned in a fire may be defined as follows:

Area Burned = A = R x t (3)

R = rate of spread.

t = time since beginning of fire.

The propagating heat flux (PF in equation (2)) is a measure of the net amount of energy reaching unburned fuel. This energy is mainly transfered by radiation. It is important to note that radiation intensity is a function of the distance from its source and may be defined as follows:

$$\text{Radiation intensity} = i = \frac{1}{d^2} \quad (4)$$

d = distance from radiation source

These theoretical considerations are discussed to increase the understanding of the reasons for the fire protection measures presented in the next section. The greater danger of fires in

full trees compared to tree lengths is predictable from equation (1) above, which indicates that fire intensity is a function of the surface-area-to-volume ratio and that fire spread rate is inversely proportional to the bulk density of the fuel. Since full trees have a higher surface-area-to-volume ratio and lower bulk density (25,28) than other forest products, a higher fire risk results.

Section 5.2 Fire Prevention and Control in Full Trees

Each of the following sub-sections details one of the fire prevention and control recommendation of this study.

Section 5.2.1 Ignition Source Control

In order for a fire to start, an initial source of high-temperature heat must be provided to ignite the fuel. One of the most important methods of fire prevention is ignition source control. This is evident in forest fire prevention programs which limit the use of fire in high risk periods. The control of ignition sources should include the following items:

A) Educational material (posters, stickers and mention in safety meetings) aimed at increasing employee awareness of fire protection needs in the plant area.

B) Rigid control of established no-smoking and smoking areas in the central processing plant and obvious designation and delineation of these areas.

C) The use of spark arresters on the exhausts of heavy equipment and smokestacks adjacent to the plant would reduce the fire risk.

D) In paved mill yards or in areas with significant stone content in soil, rubber-tired equipment will produce fewer sparks than metal-tracked equipment.

Section 5.2.2 Early Detection

Since the area burned in a fire (and therefore the quantity of wood affected) is a function of time and the spread rate of the fire (see equation (3)), the damage done by a fire may be reduced significantly by reducing the length of time between the start and extinction. In many of the operations visited a continuous watch was kept on the central processing yard (18,26). In situations where the fire risk is severe, infrared temperature sensors geared to an alarm system could be used to monitor the inventory for the hotspots caused by a fire.

Section 5.2.3 Initial Attack

Once a fire has been found, damage can be minimized by immediate extinction. This can only be achieved if the following conditions exist:

A) Adequate equipment is ready in working order and is sufficiently accessible.

B) Trained personnel are available to operate fire fighting equipment.

Figures 17 to 20 show the fire fighting equipment which was available in central processing yards in Western Canada. Figures 17 to 19 snow different variations of fire trucks and trailers with water holding capacities ranging upward from approximately 2,200 1. Figure 20 shows a box containing a gravity-fed water hydrant which was part of the fire-fighting equipment in one operation visited (27). In many cases standard portable fire-fighting pumps and hoses were available to make possible the utilization of water from streams adjacent to the central

processing yards. The identification and dissemination of information regarding the authorities to contact for firefighting assistance among employees could also reduce damage due to fire.

Section 5.2.4 Moisture Content Control

It is evident from Equation (1) that fire intensity is inversely proportional to the moisture content of the fuel. This has important ramifications for fire prevention.

During the season in which fires normally occur, trees which have been longest in inventory should be processed first to reduce the drying time and, thereby, to keep the moisture content as high possible. This strategy can also reduce breakage in handling (see Section 4.2).

The moisture content of the trees may also actively be increased by addition of water to trees. Figure 21 shows a sprinkling system used in a West German central processing plant (5) which was designed to reduce beetle damage, but which also serves as a fire protection mechanism. The fungus growth also visible in these pictures causes only superficial damage. The practice of spraying wood inventories with water to prevent fire and drying damage is common in the forest industry (17).

Section 5.2.5 Provision of Fire Breaks in Wood Piles

Breaking the piles of full trees in inventory into blocks separated by fuel-free spaces will reduce the risk of fires spreading. The spread rate of a fire is a funtion of the rate of heating of unburned fuel, see equation (2). The intensity of radiation decreases with the square of the distance from the

source. These two relationships indicate that the physical separation of burning and unburned fuel can slow or stop fire spread. The fact that radiation intensity drops off quickly with increasing distance implies that relatively small breaks may be quite effective. The prevention or minimization of fires caused when spraks are transported through the air from burning piles may require larger breaks. Since the storage of full trees will occur in areas where land values are high, the creation of fire breaks may increase land costs by reducing the effective occupation of the land in the yard. The optimal break size will be that for which the sum of fire costs and land costs is at a minimum.

Section 5.2.6 Yard/Equipment Sanitation

The removal of accumulated flamable debris (branches, needles and tops) from areas adjacent to the central processing plant and mobile equipment is an important part of fire prevention. In one operation visited, several hours per week are devoted to yard cleanup (11). The accumulation of debris in this operation prior to cleanup is shown in Figure 22.

Section 5.2.7 Inventory Size Reduction

By reducing the size of the full-tree inventory, the quantity of wood at risk at any time is reduced. The optimal size of the inventory may be determined by evaluating a total cost function which is composed of the cost of a fire (increases with inventory size) and cost of shutting down due to

insufficient inventory (decreases with inventory size). The break up inventory required can also be reduced by scheduling long repairs and maintenance for the break up period.

Section 6.0 Other Handling and Storage Considerations

Section 6.1 Alignment of Butts

Full trees are significantly more variable in length than tree lengths (25). The practice of aligning the butts at roadside using a skidder blade would cause excessive branch and top breakage. This implies that there may be some variability in the distance of the butt from the front of the trailer (see Figure 23). Figure 24 shows the difficulties which may arise from the lack of alignment of butts. This kind of difficulty could have been avoided if the first stake had been placed further toward the rear of the trailer. This phenomenon may make the bottomless extensible trailer less desirable for the transport of full trees. Figure 25 show a trailer designed for the transportation of full trees which would avoid the difficulties mentioned above.

Section 6.2 Sweeping of Road Fines

Handling full trees with full crowns and long stems can cause problems with sweeping of "fines" (the fine soil particles found in unpaved roads). This is cause by the brushing action of tops and branches on the road surface. This effect may be eliminated by installing 15-20 cm blocks in the rear portion of the floor of trailers to raise the tops and branches off the ground (26). The tops of very long trees may also be trimmed. Figures 25 and 26 show tops and branches dragging. Figure 27

shows a load carried in a truck with the lifter block built into the trailer.

Section 6.3 Inventory Holding Costs

The high capital costs of forest harvesting and processing equipment requires that a high degree of utilization be maintained in order to be economically justifiable. A certain amount of "inventory in process" is maintained between the various steps in the harvesting systems. This inventory buffers each process from those preceeding it. The full-tree central processing plant is no exception to this rule. A large full-tree inventory would be required to buffer the plant process from weather-related hauling difficulities (such as heavy snow) and to maintain operation during the spring break-up.

The maintenance of inventory in process incurs costs which are a function of the average cost of processing invested in the inventory and of the cost of borrowing to finance this inventory. Figure 29 shows the relationship between inventory holding cost, processing cost investment and interest rates. It should be obvious that, as the size of the inventory increases, inventory holding costs increase. It is important to note that most tree-length or shortwood systems also have inventory in process. Since full trees delivered to a central processing plant have a lower processing cost investment than tree lengths or shortwood, the unit inventory holding costs will be lower. The net difference in total inventory holding costs between the full-tree and tree-length or shortwood systems will depend on the size of the inventory. The costs associated with fire damage in

inventory (should this occur) will be higher in full trees and may, therefore, offset lower inventory holding costs. Several forest managers in western Canada indicated that lower unit inventory holding cost was one of the benefits associated with central processing yards (18,19).

Section 6.4 Dimensional Control in Full-Tree Loads

Full tree loads, particularly in the smaller trees found in eastern Canada, are more "bushy" and may, therefore, interfere with passing manoeuvers. Figures 30 and 31 show loads of black spruce and jack pine (in combination). The problem of dimensional control has been dealt with in Silversides (1985). European operations hauling small trees use trailers with enclosed sides and bunks to alleviate problems with protruding branches (5). Figure 25 shows a trailer of this type, which may be contrasted with the conventional North American trailer shown in Figures 27 and 30.

Section 7.0 Preliminary Experimental Design

When a central processing plant is built and tested, the breakage of full trees and tree lengths or shortwood may be compared. This section outlines the form which the experiment should take in order to achieve the following objectives:

1) To determine whether there exists a statistically significant difference in the breakage rate and merchantable volume loss between the full trees delivered to the central processing plant and tree lengths or shortwood delivered the same distance.

2) To identify the amount of breakage in each of the process steps unique to the full tree system.

3) To identify the impact of the following 'non-process' factors on the quantity of breakage:

a) tree species
b) season
C) duration of storage.

Section 7.1 General Considerations in Experimental Design

Statistical sampling of logging operations, especially involving large numbers of individual trees, is an expensive exercise. The need for information about breakage must, therefore, be firmly established before sampling is undertaken. A preliminary estimate of gross total breakage in full trees and shortwood or tree lengths delivered to the mill must, therefore, be obtained. These breakage rates should then be compared to determine whether a statistically significant difference exists. If the difference is not significant, no further testing is warranted. If the difference is statistically significant, one further question must be asked. Is the difference sufficient to warrant action? If the answer to this question is negative, no further testing is warranted. If the answer is positive, further testing should be undertaken. The following sections will provide the outline for the testing methods.

Since the experiment being designed will be carried out in the context of the test of a prototype central processing plant, the initial startup period of both the plant wood handling equipment and the full-tree loading and hauling systm feeding it will be characterized by higher than normal breakage and lower than normal productivity. This is a phenomenon often experienced when testing new equipment. Any test of breakage must, therefore, be carried out after productivity and breakage have

stabilized. This may require several weeks or months. This stabilization period is critical since results may be seriously biased by inclusion of data gathered in the startup period.

Section 7.2 Variables Measured

Breakage is important because it can cause the following effects:

1) reduced energy biomass recovery
2) reduced 'merchantable' volume recovery
3) reduced product value (shortening of sawlog).

In order to assess the severity of these effects, several variables must be measured during sampling:

1) condition at top of stem
2) diameter at top of stem
3) butt diameter
4) length of tree stem.

Variable 1) is a discrete variable whereas variables 2) to 4) are continuous in nature. The determination of minimum sample sizes is approached differently for these two classes of variables (29). Sample size selection will be dealt with in subsequent sections.

Section 7.3 Factors Affecting Sampling

Although a host of factors will affect the quantity and quality of breakage, the four variables listed below represent those of greatest importance under normal conditions:

1) operator skill, training and motivation
2) variation in tree size and quality (e.g. dead/live)
3) weather (ambient and past)
4) duration of storage.

The influence of operators on results is often critical. A review of machine evaluations by organizations such as the Forest Engineering Research Institute of Canada (FERIC) reveal frequent references to this. There are two means of negating or reducing operator-induced error. The first of these is to perform the test with full trees and tree lengths or shortwood using the same operator. The second is to use a large number of operators, hoping that the error will be randomly distributed. The use of the same operator in both full-tree and conventional systems may be limited by the need to run operations simultaneously (to remove the effect of weather) or by the need to move more wood than may be handled by one operator. The use of a large number of operators would be more desirable. A note of caution with regard to the selection of operators is advised: the use of volunteers may lead to the use of unrepresentatively large proportions of motivated operators, with a resultant bias in favour of decreased breakage.

The effect of differences in tree sizes and quality can be overcome only through careful selection of test stands and recording of stand and timber characteristics. This effect can also be reduced by sampling a large number of stems. Selection of stands in close proximity may also reduce the difference in tree size and quality.

The effect of weather conditions can be negated or minimized by running tests of both the full-tree and conventional systems simultaneously and in close proximity. Careful recording of data will also aid in identifying the effect of weather.

The effect of duration of storage can be reduced by ensuring

that similar storage times are used for full trees and tree lengths or shortwood and that careful records are kept.

Section 7.4 Sampling Method

Section 7.4.1 Preliminary Sample

The first step in the sampling method is to perform a preliminary study of the breakage. Although the sample size required will vary with the variability of the breakage (induced by a host of factors, four of which are listed in Section 7.3), the number 400 might suffice. Appendix A shows how the breakage data reported in (24) can be used to estimate sample sizes. The figure 400 assumes a desired 95% confidence interval and the extended storage of balsam fir (a fragile species) in winter conditions.

In the preliminary analysis, the sample should be drawn as close to the endpoint as possible in the processing system. This will capture as much of the total breakage as possible. In the case of the full tree central processing system, the trees should be sampled after they have been retrieved from inventory. In the tree length system, the trees should be sampled immediately before they are bucked.

The total number of samples should be distributed over as large a number of trees as possible to increase the degree to which the sample will be representative of the trees processed. This strategy is limited by the relationship between sampling cost and the number of trees sampled per grapple load, pile,

truck load, etc. As the number of trees sampled per grapple load decreases, the cost per tree sampled increases. The appropriate number will need to be determined when the sampling cost can be assessed (i.e. once the prototype plant is built).

The trees to be sampled will be selected as follows:

1) Determine the total number of stems in a grapple load, truck load or pile.

2) Select the number of stems (determined once the relationship between sampling intensity and cost is known) to be sampled and, randomly select them from the total number of stems.

3) Dismantle the grapple load, truck load or pile one tree at a time using a loader and being careful not to induce breakage. Set aside trees to be measured (the random selection will have created a list of stem numbers such as 10, 26, 49, etc. which means "select the tenth, twenty-sixth, and forty-ninth stems to be removed from the pile").

4) For each tree selected, measure and note the following:

   a) butt diameter
   b) presence of broken top
   c) diameter at break
   d) length of stem
   e) presence of ice and snow build-up in top
   f) species
   g) condition (alive/dead).

There is a small possibility that a tree might be broken at the butt end. It is possible, should such a tree be included in the sample as a separate stem, to cause double counting of volume lost and breakage since the stem section with the intact butt will also be counted. It is, therefore, suggested not to include trees with broken butts in the sample tally as separate stems.

This sampling will permit the creation of a volume function (based on butt diameter) which can be used to estimate breakage volume loss as a function of the diameter at the break and the

stem length. The breakage as a function of tree size, species, condition and ice/snow build-up will also be definable. The variance estimates obtained from this preliminary sampling will be useful in estimating sample sizes required to achieve the desired level of significance.

The proportion of stems broken in the merchantable area as full trees and tree lengths may then be compared using a chi-squared test (29) to determine whether a statistically significant difference exists. The mean merchantable volume loss in full trees and tree length may then be compared using a Student's t-test (29).

Section 7.4.2 Main Sampling

Once the need for further sampling has been determined, the individual steps in the process must be examined to identify breakage sources. In many cases, both the full-tree system and the tree-length system will have certain steps in common. Only steps in the full-tree system which are different from those used in the tree length system and in which breakage is feasible (see Section 3.3 for a discussion of the steps in which differences are possible). If one process step is found to cause the majority of the incremental breakage in the full- tree system, it may be unnecessary to sample the other steps. Sampling individual process steps may be done by using a sampling method identical to that used in the preliminary sampling except that trees which are not broken need not be measured (since a volume table will already have been constructed). The sample size will be determined by the ratio of broken to unbroken stems in the preliminary sample.

The development of a detailed experimental design can only be undertaken when the make-up of the full-tree and tree-length or shortwood systems which feed the prototype central processing plant are known. The general guidelines given herein can serve as a framework for the final experimental design.

Section 8.0 Conclusion

Although no scientific evidence could be found to support fears that full-tree handling causes more breakage than tree-length or shortwood handling, it is clear that some incremental breakage can be expected. The significance of the difference in breakage is unclear. Discussions with woodland managers have indicated that breakage in full-tree handling is manageable when handling methods are adapted to this product. The high breakage reported in most full-tree hauling and handling tests is at least partly a function of operator inexperience or of factors within the control of forest managers.

The fire risk in stored full trees is clearly higher due to their physical characteristics. This problem also appears to be manageable if appropriate fire prevention and control measures are used. There is little operational experience in North America or Europe with fire prevention in large full-tree inventories. Such expertise will have to be developed domestically.

Although many operations in western North America have used central processing yards, the reasons for doing so have been largely unrelated to the recovery of branch and top biomass for

use as a fuel. A long list of advantages are cited to justify the operation of central processing yards (9). Some of these advantages include:

1) Improved skidding, loading, log processing and hauling productivity.

2) Improved crew safety (by reducing the amount of work in the stump and landing areas).

3) Lower crew transportation costs.

4) Improved log sorting.

5) Improved log quality.

6) Reduced cost of landing construction.

Operations in which central processing has succeeded in western North America have been characterized by combinations of the following traits:

A) High value products may be produced from the logs.

B) Long off-highway hauls are possible.

C) Landing construction costs are high.

D) Markets for energy products and full-tree chips exist.

The form of many western tree species (long, limb-free stems) reduces the merchantable volume differential between full-tree and tree-length or log-length loads. It is, therefore, as advantageous to haul large oversized loads of full trees as any of the other products. In eastern species, the crown extends over a greater portion of the stem, thereby reducing the merchantable load which may be carried as full trees. In the East , long hauls mitigate against full-tree systems rather than the opposite in the West.

In Europe, the combination of short hauls, high product values and a well-developed market for energy biomass make the central processing option attractive.

Central processing of full trees has the highest potential to be economically attractive when energy has a positive value, hauls are short and product values may be maximized by concentration and processing at a central plant. The economics improve substantially when the system being replaced is highly labour-intensive. It should be clear that the central processing concept must be 'sold' on the basis of the sum total of its advantages rather than solely on the basis of its potential to recover energy biomass.

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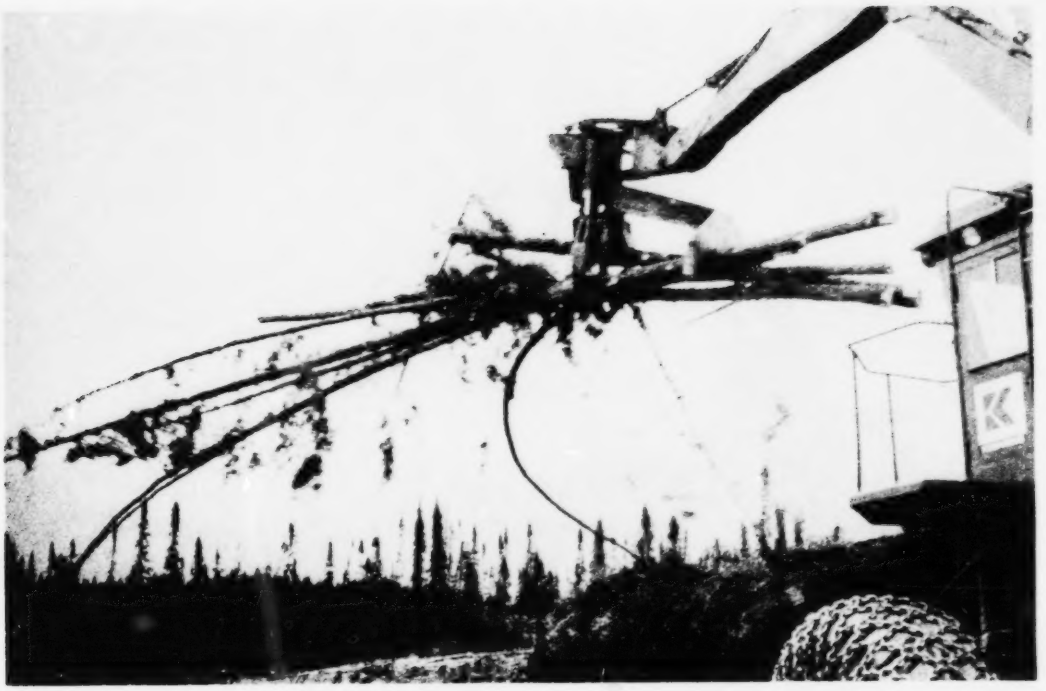

Figure 1 Heel-boom loader with a load of full trees- unloading. (Gogama, Ontario).

Figure 2 Heel-boom loader with a load of full trees- trees are "fanning out". (Gogama, Ontario).

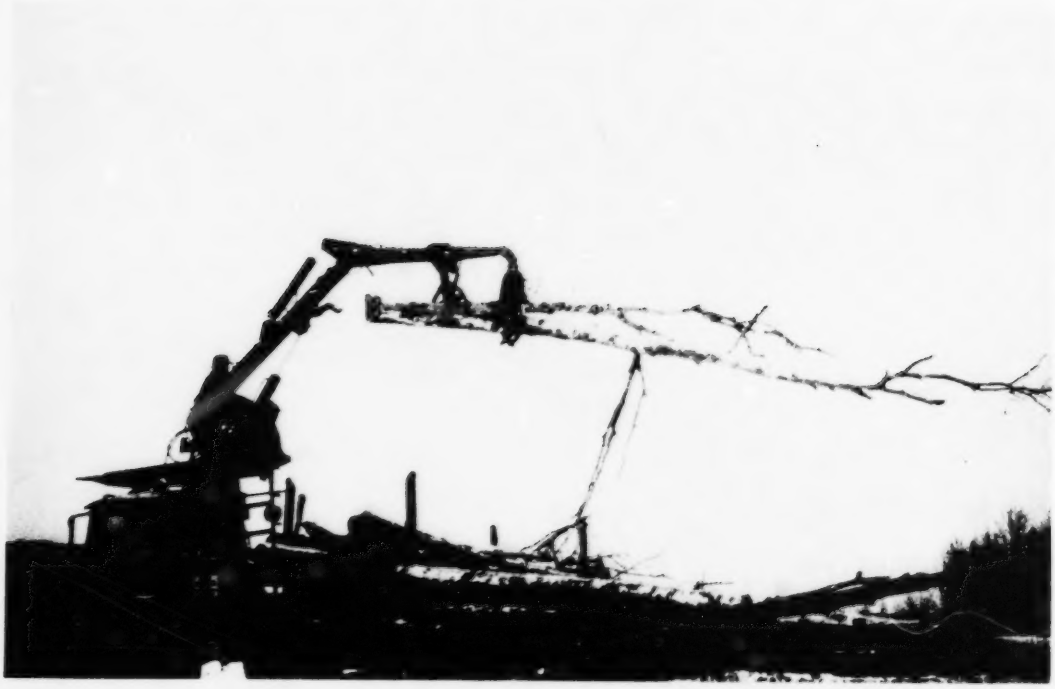

Figure 3 Heel-boom loader with a load of hardwood full trees. (Alberta). Courtesy of W. Ondro, Canadian Forestry Service.

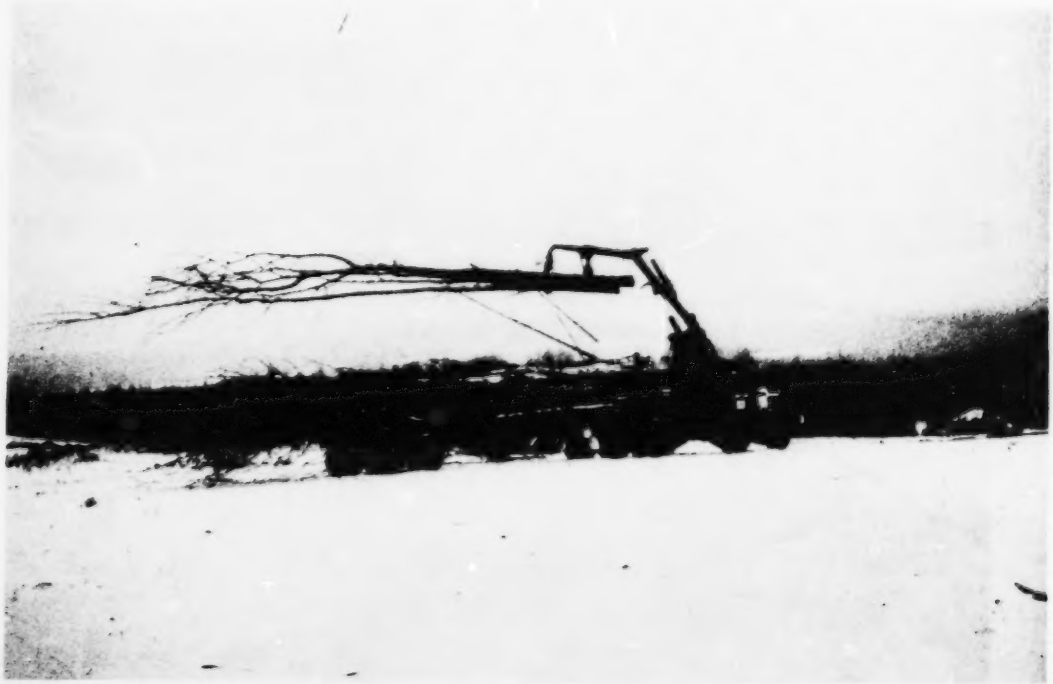

Figure 4 Heel-boom loader with a load of hardwood full trees. - notice trees falling from grapple (Alberta). Courtesy of W. Ondro, Canadian Forestry Service.

Figure 5 Heel-boom loader with a load of full trees - load is handled cleanly. (Kelowna, B.C.).

Figure 6 Heel-boom loader with a load of full trees - load is handled cleanly. (Kelowna, B.C.).

Figure 7 Heel-boom loader with a load of full trees - load is handled cleanly. (Port Angeles, Washington). Courtesy of W. Hermann, Hermann Brothers Logging.

Figure 8 Heel-boom loader with a load of full trees - load has fanned out. (Port Angeles, Washington). Courtesy of W. Hermann, Hermann Brothers Logging.

Figure 9 Center-grab loader with a full tree. (Donaueschingen, West Germany). Courtesy of P. Dietz, Furstenburg Forest Directorate.

Figure 10 Center-grab loader with a full tree. (Donaueschingen, West Germany). Courtesy of P. Dietz, Furstenburg Forest Directorate.

Figure 11 Center-grab loader (mounted on a jib-crane) with a load of full trees - trees are handled cleanly. (Timmins, Ontario). Courtesy of D.D. Hamilton, Logging Development Corporation.

Figure 12 Truck load of full trees - note large tree size. (Kelowna, B.C.).

Figure 13 Full trees being loaded on a trailer. Note large tree size. (Kelowna, B.C.).

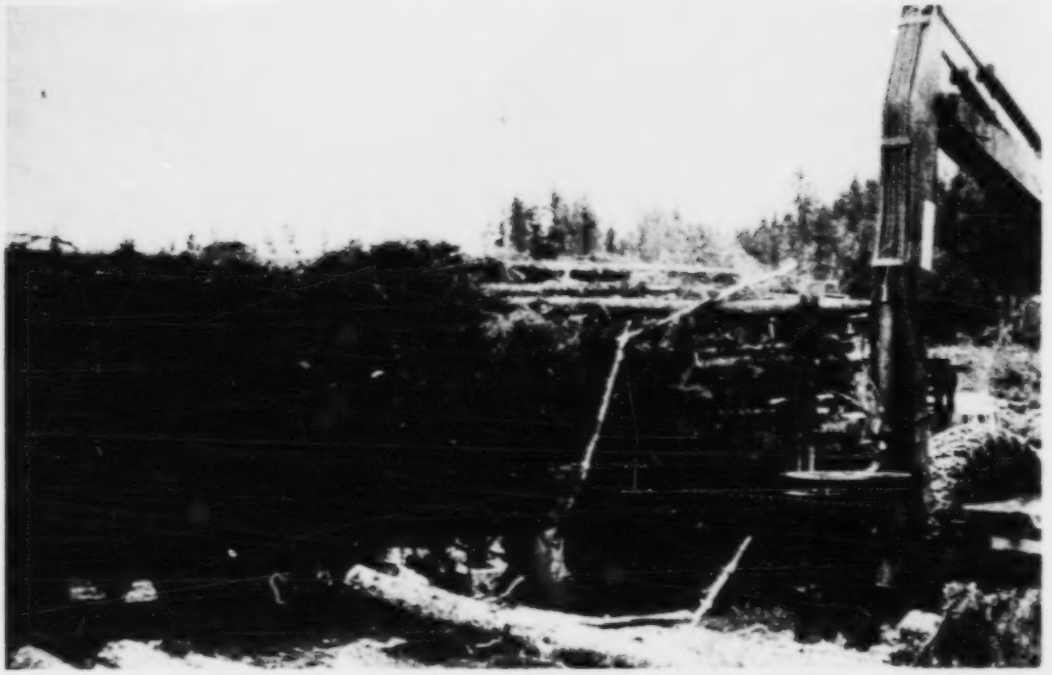

Figure 14 Load of full trees - note small tree size. (Gogama, Ontario).

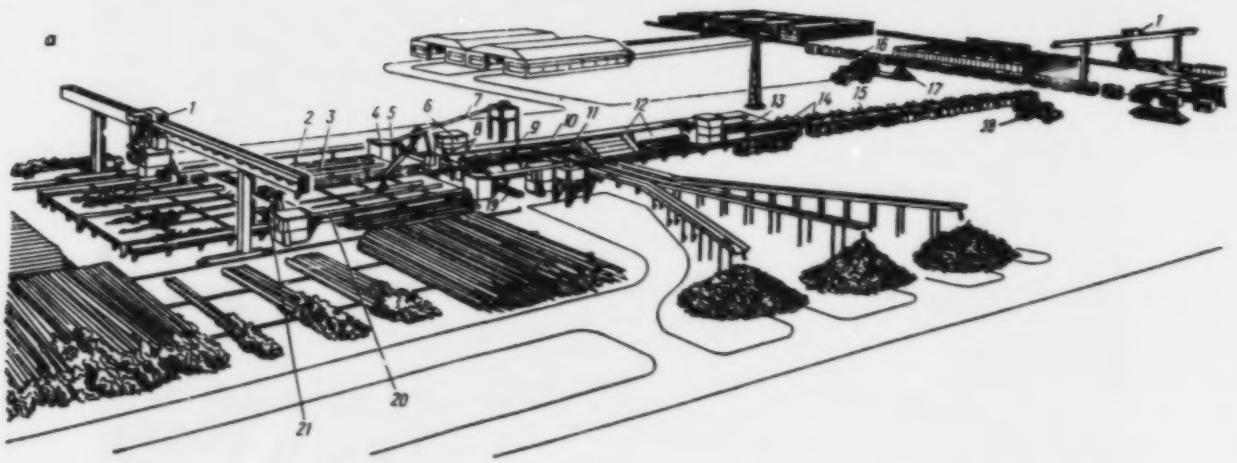

Figure 15 Drawing of central processing plant of type used in the Soviet Union - note presence of center-grab loader on portal crane (label "1"). Courtesy of J. Holowacz, Canadian Forestry Service.

Figure 16 Fire in widely spaced jack pine trees. Courtesy of D.L. Martell, University of Toronto.

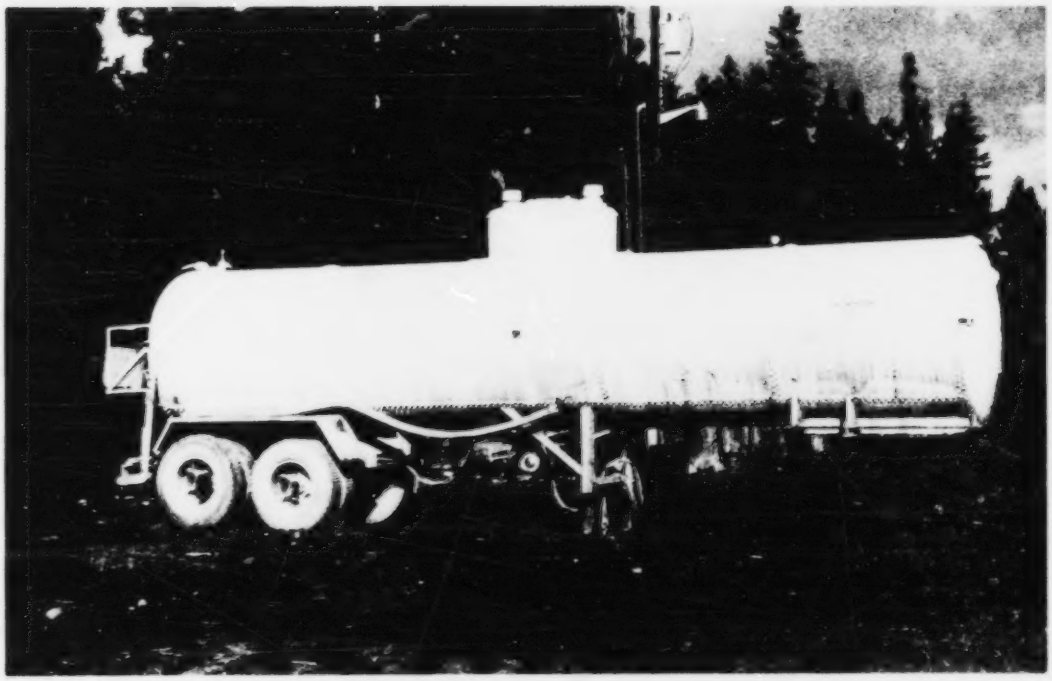

Figure 17 Fire-fighting water tank (4500 l capacity) near central processing yard. (Kelowna, B.C.).

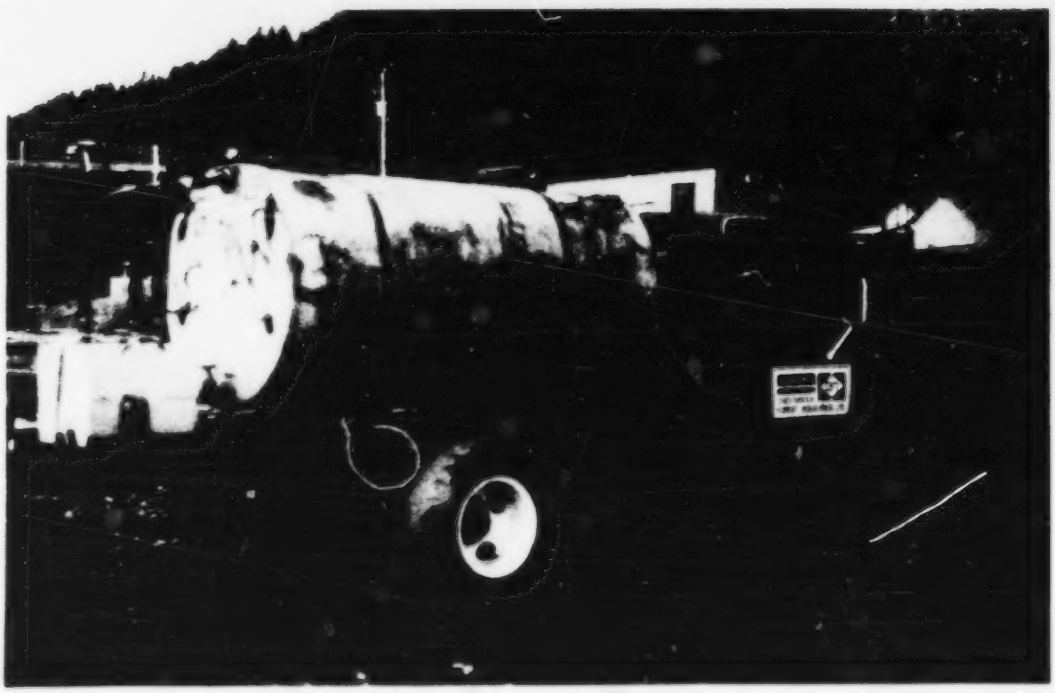

Figure 18 Fire-fighting water tanker truck (2200 l capacity) in reload yard. (Parson, B.C.).

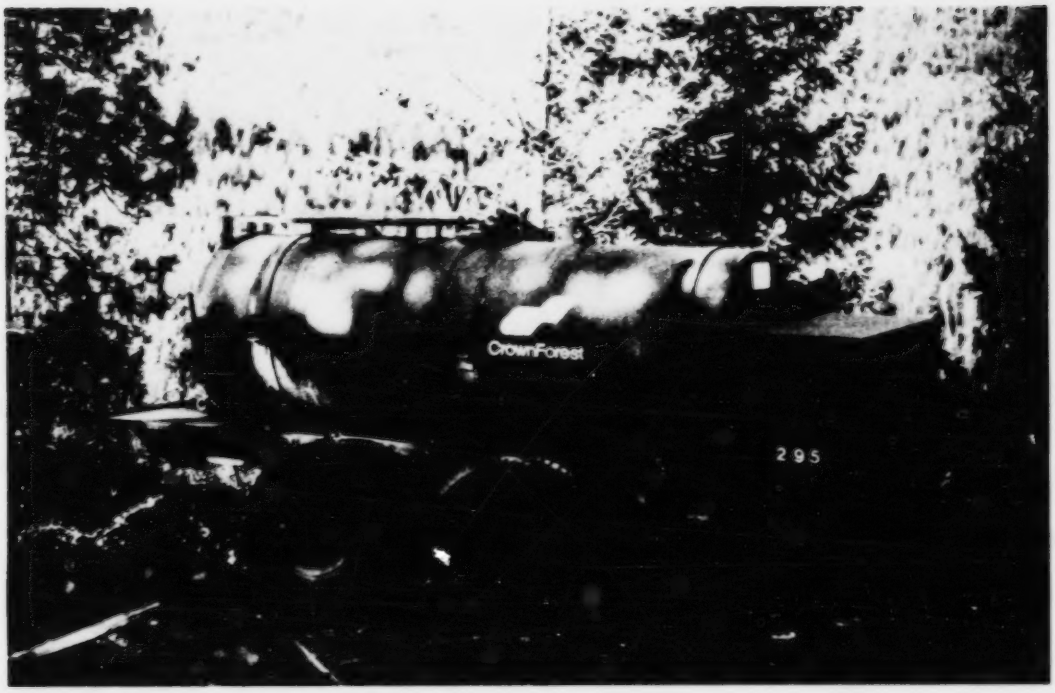

Figure 19 Fire-fighting trailer (2200 l capacity) near central processing yard. (kelowna, B.C.)

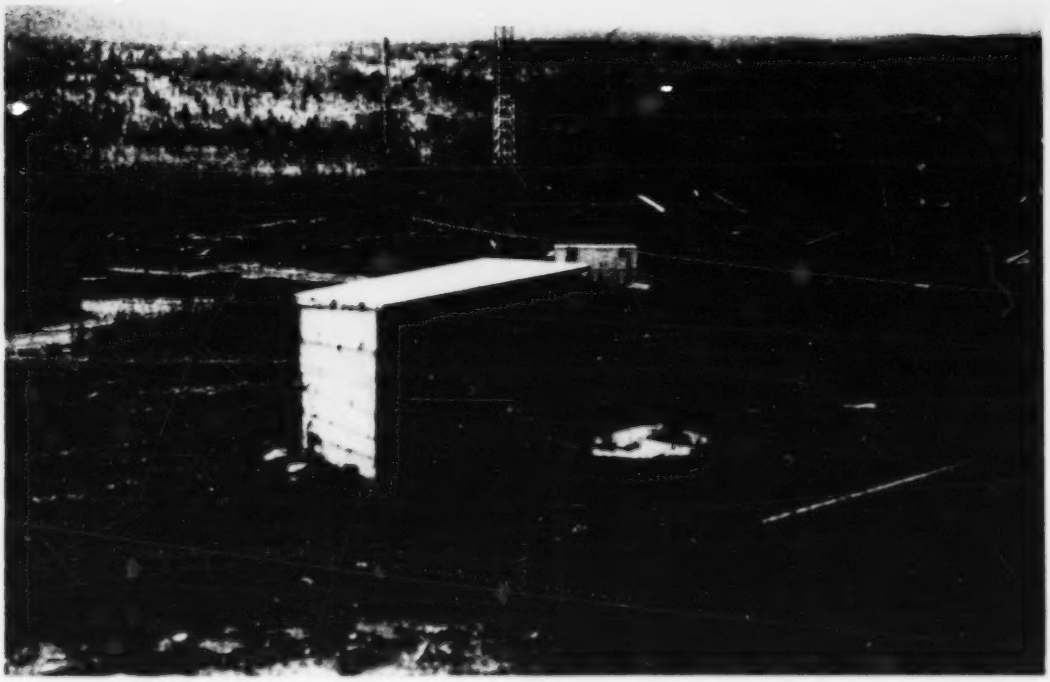

Figure 20 Insulated housing for a gravity-fed hydrant (one of four) in reload yard. (Parson, B.C.).

Figure 21 Sprinkler tower in tree-length inventory of central processing plant. Fungus growing on butts causes only superficial damage. (Donaueschingen, West Germany).

Figure 22 Debris accumulated in central processing yard before weekly cleanup. (Port Angeles, Washington). Courtesy of W. Hermann, Hermann Brothers Logging.

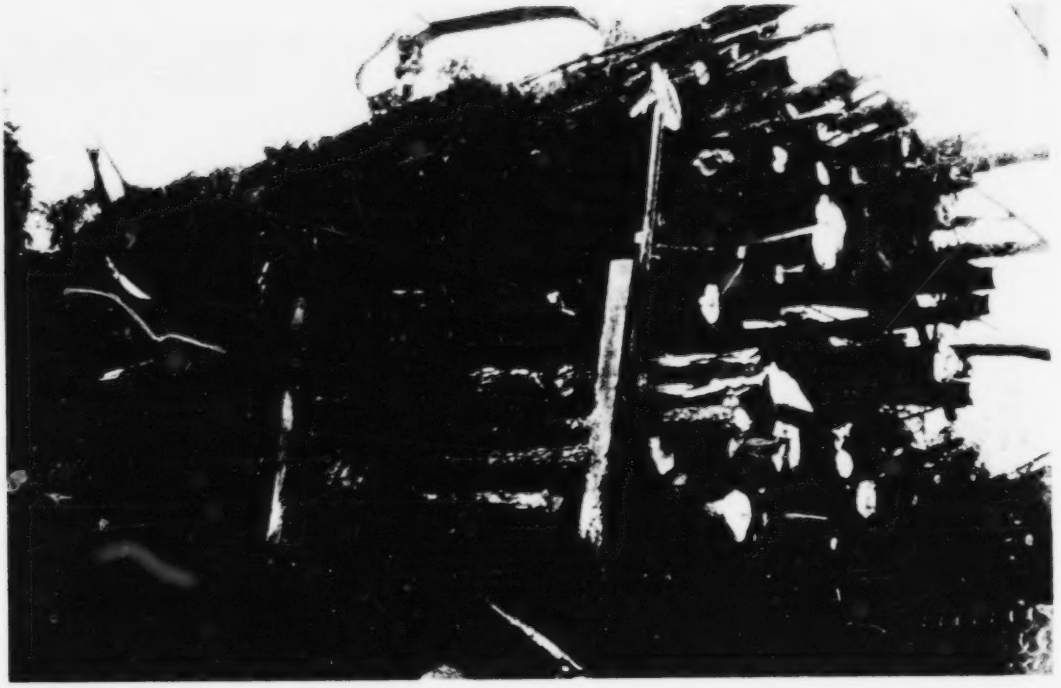

Figure 23 Uneven butt alignment on full-tree truck load. (Port Angeles, Washington). Courtesy of W. Hermann, Hermann Brothers Logging.

Figure 24 Tree escaped from load causes road damage and stops truck due to poor butt alignment. (Alberta). Courtesy of W. Ondro, Canadian Forestry Service.

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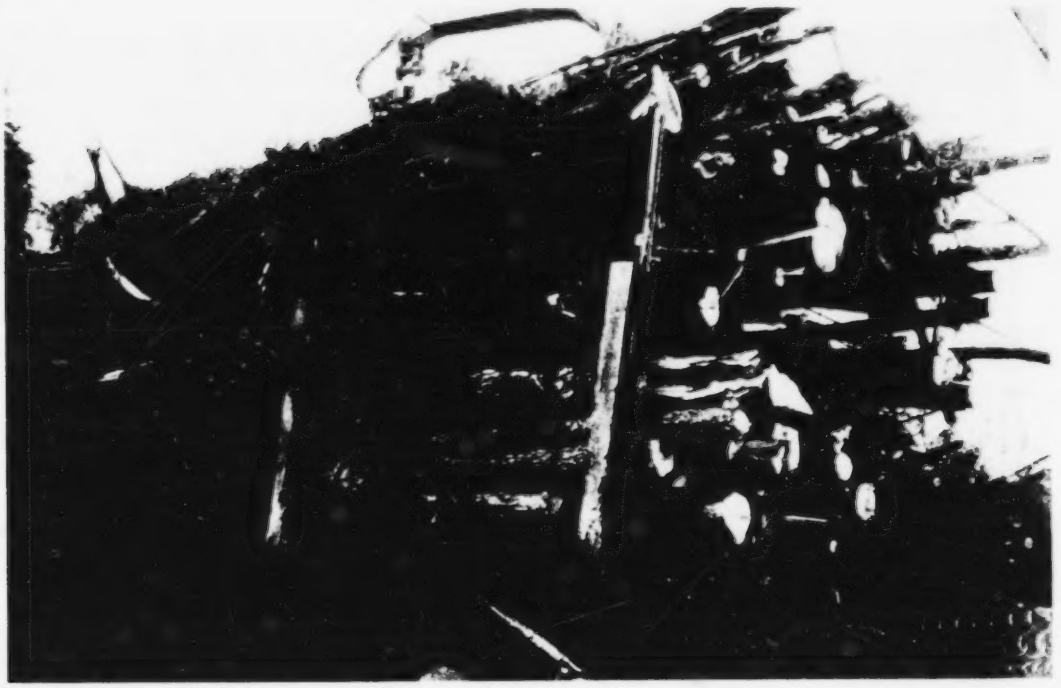

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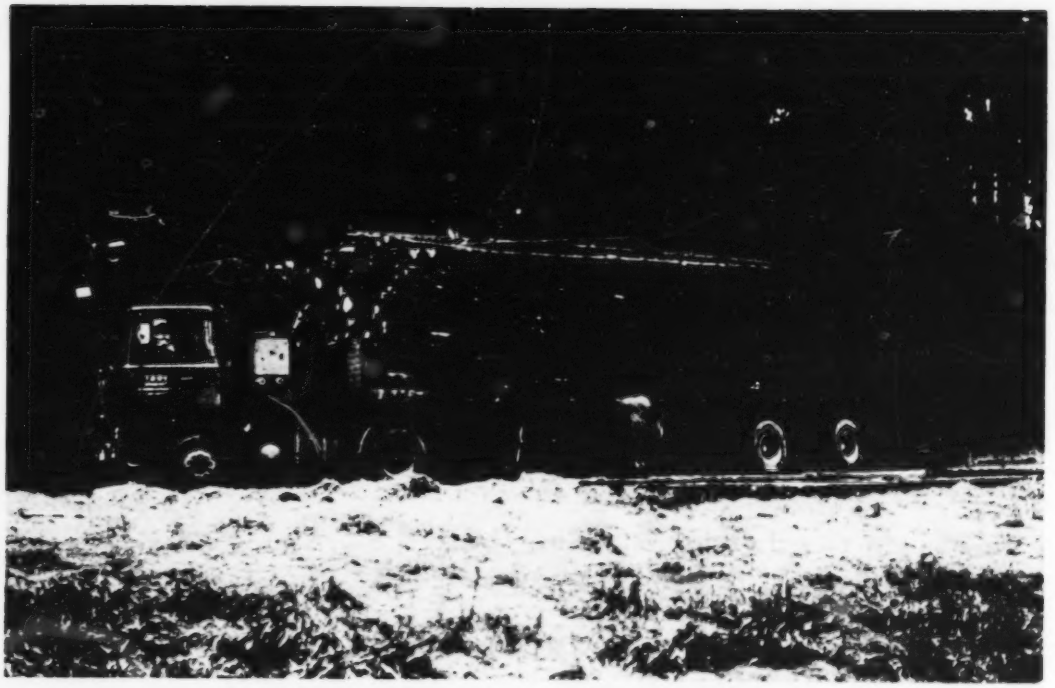

Figure 25 West German full-tree trailer with floor and enclosed sides to prevent escape of trees and to control load dimensions. (Donaueschingen, West Germany). Courtesy of P. Dietz, Furstenburg Forest Directorate.

Figure 26 Load of hardwood full trees - note contact between branches and ground at rear of load.(Alberta). Courtesy of W. Ondro, Canadian Forestry Service.

Figure 27 Load of full trees with long tops scraping road. (Port Angeles, Washington). Courtesy of W. Hermann, Hermann Brothers Logging.

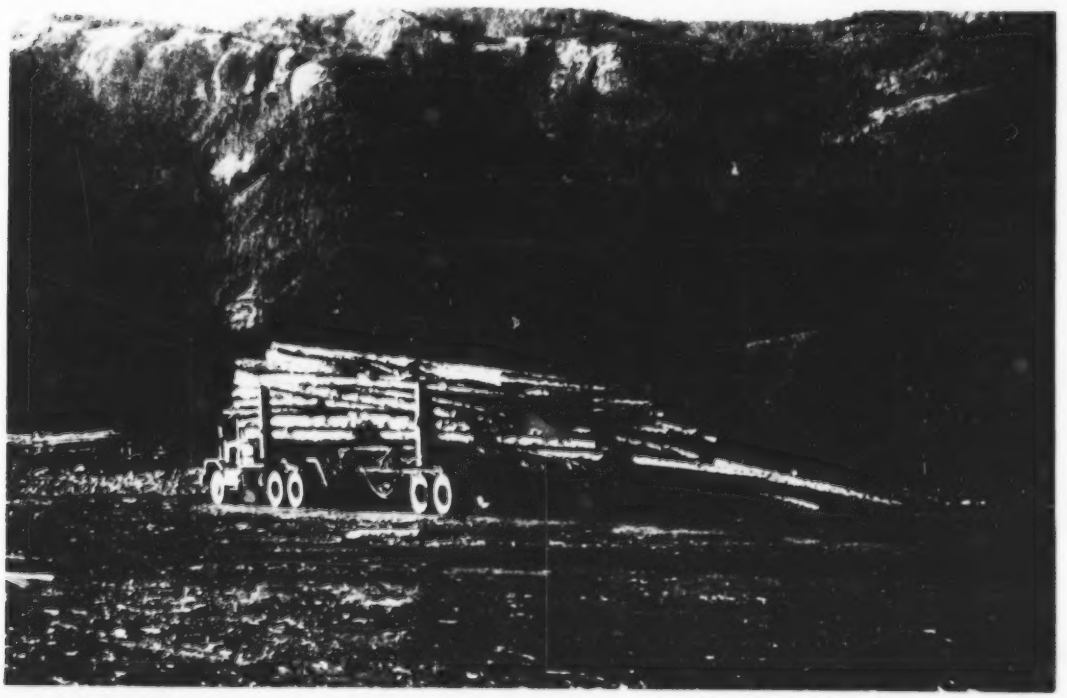

Figure 28 Load of full trees in trailer equipped with a 20 cm block at the rear stakes to raise the rear of the load - note that long tops are not touching soil. (Kelowna, B.C.).

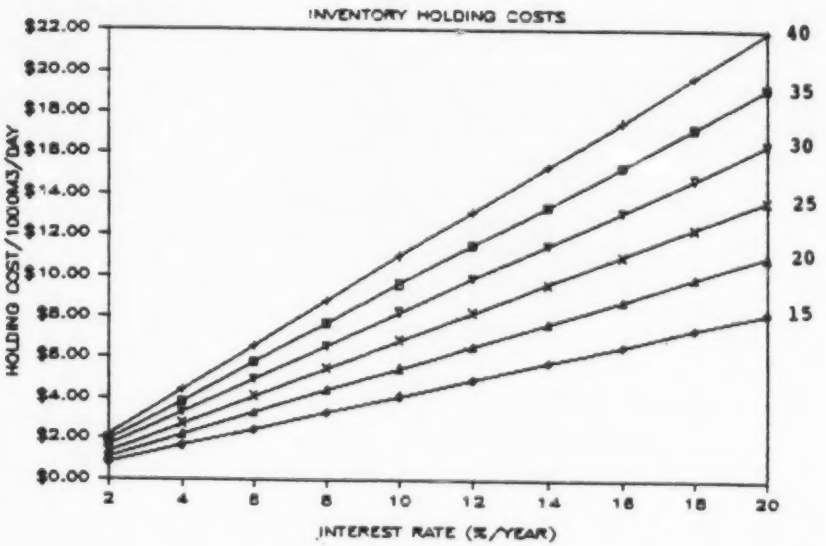

Figure 29 Graph of unit inventory holding cost versus interest rates for various processing cost levels.

Figure 30 Full tree truck load showing dimensional control difficulties. (Timmins, Ontario). Courtesy of D.D. Hamilton, Logging Development Corporation.

Figure 31 Full tree truck load showing dimensional control difficulties. (Timmins, Ontario). Courtesy of D.D. Hamilton, Logging Development Corporation.

APPENDIX A

Determination of Sample Size for Breakage Estimates

The proportion of stems broken during handling is a discrete variable (i.e. broken/unbroken). Reese (1962) describes a method used to estimate the sample size required to obtain an estimate with a know probability of error. The formula used is:

$$n = \frac{1}{\frac{E^2}{(4)(P)(1-P)} + \frac{1}{N}} \quad \ldots(1)$$

where,

n = sample size required to achieve probability of error of 0.05

E = accuracy required (0.05)

N = size of population (in the case of a mill handling 300,000 m this would be in excess of two million trees)

P = estimated proportion of trees exhibiting breakage

(4)= factor used if probability of error is 0.05.

Since the population, N, is very large, the term containing population in equation (1) will tend to zero. The formula can then be rewritten as follows:

$$n = \frac{4(P)(1-P)}{E^2} \quad \ldots (2)$$

Since E is 0.0025 for a probability of error of 0.05, the equation can be written:

$$n = 1600(P)(1-P)$$

Using the broken/unbroken proportions found in Routhier (1981), the following sample sizes can be calculated:

1) for black spruce harvested in September, hauled in January:

$P = 0.125$, $n = 1600(0.125)(1-0.125) = 231$

2) for black spruce harvested in January, hauled in February:

$P = 0.084, \quad n = 1600(0.084)(1-0.084) = 123.2$

3) for balsam fir harvested in September, hauled in January:

$P = 0.42, \quad n = 1600(0.42)(1-0.42) = 389.8$

4) for dead balsam fir harvested in January, hauled in February:

$P = 0.26, \quad n = 1600(0.26)(1-0.26) = 307.8$

It is interesting to note that in three of the four cases described above, the size of sample taken in Routhier (1981) are insufficient to ensure a 0.05 confidence level. This, of course, could not have been known at the time of the experiment since the proportion was not calculated until after the experiment was complete.